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IN THE UNITED STATES PATENT AND TRADEMARK OFFICE

In re Application of

Xiang-Dong Mi, et al

VERTICALLY ALIGNED LIQUID CRYSTAL IMAGING COMPONENT WITH COMPENSATION LAYER

Serial No. 10/020,543

Filed 30 November 2001

Group Art Unit: 2871

Examiner: Zhi Qiang Qi

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Deidra L. Mack
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February 3, 2006
Date

Commissioner for Patents
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Sir:

DECLARATION OF TOMOHIRO ISHIKAWA
UNDER 37 CFR 1.132

I, Tomohiro Ishikawa, of the County of Monroe, State of New York, USA, declare as follows

1. I have been trained as a Liquid Crystal Display engineer, having the following educational experience

1990 M.S. in Material Science:
Nagoya Institute of Technology
Cement crystallography and physics of inorganic glasses.

1990-1992 Research Scientist, Toyota Central Research Laboratory, Japan
Functional and structural advanced ceramics materials.

1994-2000: Ph. D. in Chemical Physics
Specializing in the physics of liquid crystals and display application
Liquid Crystal Institute, Kent State University

1. Course works (partial): Optics of Liquid Crystal, Liquid Crystal Elasticity, Statistical Physics, Physics of Liquid Crystal Displays

2. Research Activity: Defects in Liquid Crystal Material, Optical properties of liquid crystal materials, Optical device application of liquid crystals

2000-2001: Post Doctoral Fellow, Liquid Crystal Institute, Kent State University
Specialized in optical application of liquid crystals

Research activities:

A: Optical shutter using cholesteric liquid crystals.

B: Dynamics of liquid crystal domain merging.

C: Application of liquid crystal to anti-body detection.

D: Defect structures in lyotropic liquid crystals.

Authored or coauthored 13 publications and gave 10 seminar presentations on LC topics.

2. I have been employed by the Eastman Kodak Company since August 2001 in its Research Laboratories in Rochester, New York and have been working on various projects on Liquid Crystal Display optical components.

3. I am a coinventor in the present application in which this Declaration is being filed and have read the Final Office Action dated May 4, 2005, issued in that application, including the references cited in that Office Action.

4. Specifically, I have read: US 5,747,121 (Okazaki), which discloses an O-(Oblique or tilted)-Plate compensation film for <u>Twisted Nematic</u> Liquid Crystal

Displays (TN-LCD) (column 37 50-54); US 2004/0051832 (Shimoshikiryoh) which teaches Liquid Crystal Displays with LC molecules having positive dielectric anisotropy (not vertical in Off-State); and US 6,081,312 (Aminaka) which discloses a compensator for a Vertically Aligned Liquid Crystal Display, (VA-LCD) using a negatively birefringent O-plate (Column 11 line 10-20).

5. Pursuant to my direction and control, experiments were conducted to determine what the effect on the Viewing Angle Characteristic (VAC) of the O-plate compensator for TN-LCD of Okazaki would be if used to compensate a VA-LCD as in the present invention. In another experiment, the VAC performance of the compensation film of the current invention, and the one made from negatively birefringent liquid crystal polymer according to Aminaka were compared with VA-LCDs.

6. Determination of the Viewing Angle Characteristic for the Combination in combination with a VA cell and TN cell was carried out as follows:

6.1 The Contrast Ratio calculation was determined using the software "TCO" available from Polaris Software, Kent, Ohio. The calculation consisted of three steps.

1) Calculation of the liquid crystal optic axis.
2) Construction of the optical stack
3) Calculation of the transmission.

Step 1)

Liquid crystal optic axis direction is calculated based on the liquid crystal elasticity theory. The procedure is widely used in the art and well documented in standard textbooks. The brightness is controlled by the liquid crystal optic axis direction in response to the applied electric fields. In case of a VA cell, the brightness of the display using the VA cell is controlled by an applied voltage or field that leads to a different degree in the tilt orientation. To calculate contrast ratio, liquid crystal optic axis directions correspond to both dark and bright states were obtained. Same procedure was carried out for TN cell.

Step 2)

It is necessary to construct an optical stack within the software. Each layer is characterized by the direction of optic axis or transmission axis, and thickness or equivalently, phase retardation. In case of display configuration shown in Figure 7A, the stack consists of a polarizer, a compensation film with positive O-plate as shown in Figure 6B, VA cell, another compensation film as shown in Figure 6B, and another polarizer.

Step 3)

The contrast ratio for a given set of viewing angle specified by polar and azimuthal angles (page 1 line 32- page 2 line 6) is given by the formula,

$$\frac{\text{Brightness of the bright state}}{\text{Brightness of the dark state}}.$$

Therefore it is necessary to obtain brightness of the bright and the dark state at a given viewing angle. This was accomplished by calculating the brightness of the optical stacks constructed in Step 2) for both the dark and bright states. A matrix type optical algorithm (so called Berreman calculus) was used in the software to obtain the brightness for various sets of polar and azimuthal angles. This procedure is well documented in the standard textbooks. Viewing Angle Characteristic is represented by isocontrast plot such as ones shown in Figures 9A, 9B and 9C. In iso-contrast plots, azimuthal angles of 0, 45, 90, 135, 180, 225, 270 and 315 degree are represented by radial lines while and the concentric circles represent polar angles from 0 to 80 degree with 10-degree increment in this affidavit to show the different performance in more detail. In the application, the concentric circles indicate polar angle in 20-degree increment (page 2 line 3-4). The outermost circle corresponds to the polar angle of 80 degrees.

7 Results

A) Application of the O-plate compensation film for TN-LCD to VA-LCD and vice versa.

In this section, the performance incompatibility of the O-plate compensation film designed for TN-LCD and the O-plate compensation film made for VA-LCD are shown.

US 5,747,121 teaches use of an O-plate compensation film for a TN-LCD (column 2 line 12-15, Column 7 line 60-62). The compensator has an inclined optic axis (column 7 line 60-62), and thus has a tilted or O-plate property.

FIGURE A shows the VAC of TN-LCD without any compensation film.

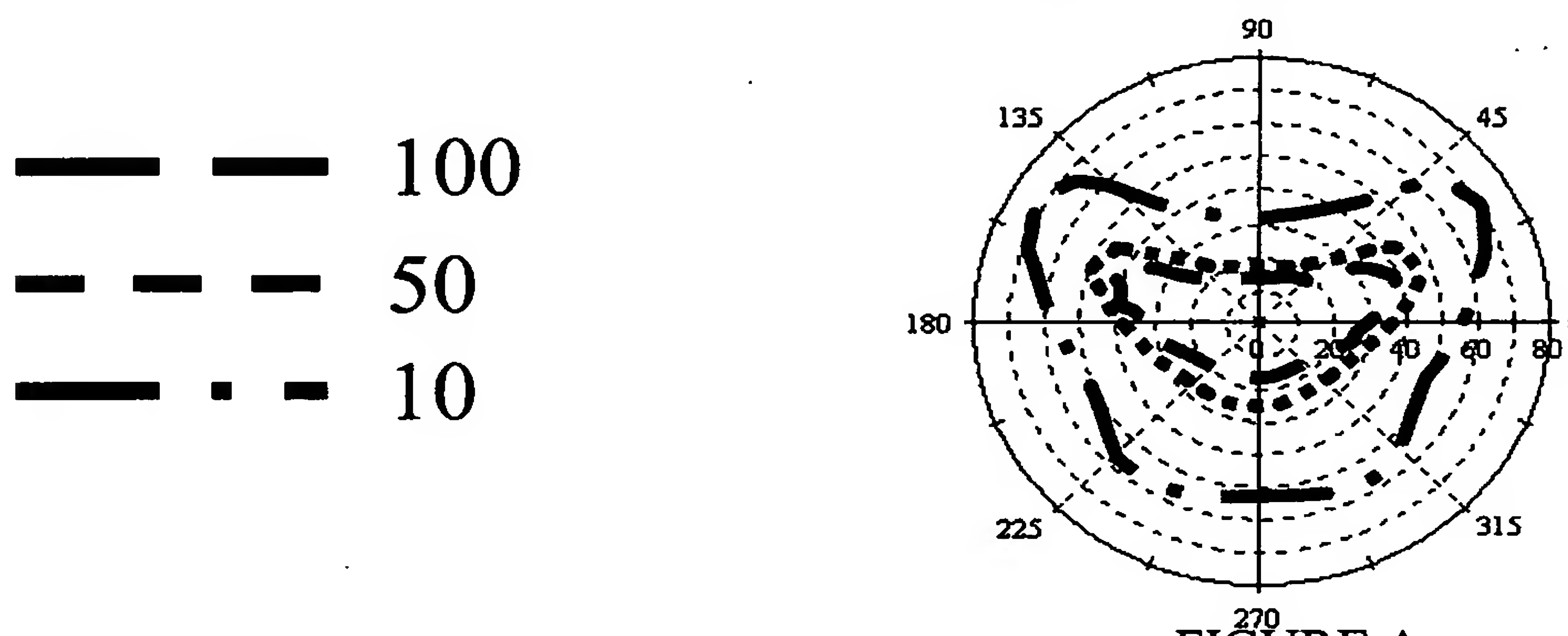


FIGURE A

Next, the compensation film in EXAMPLE 1 of the current application designed for VA-LCD is applied to the same twisted nematic display above with the following results:

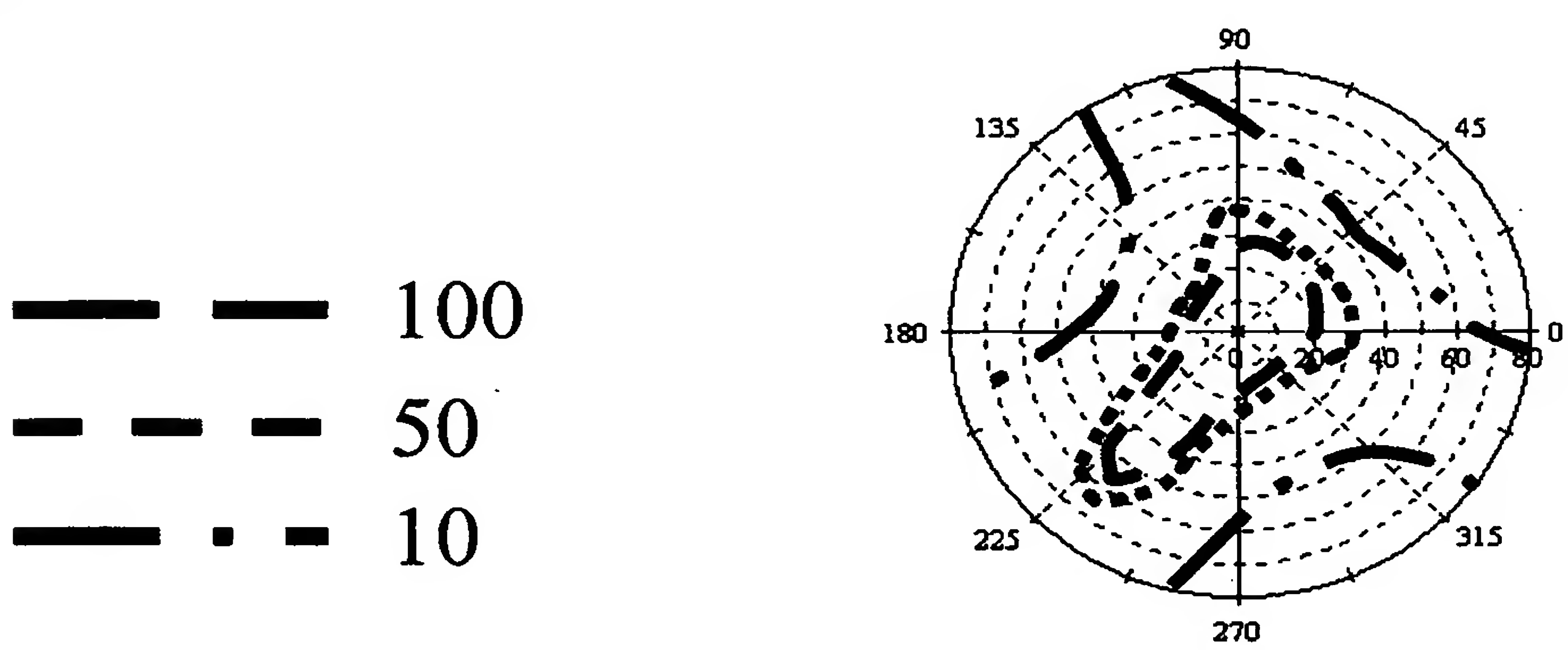


FIGURE B

The resulting VAC is shown in FIGURE B. From looking at the area bounded by the 50 contrast line, considering the uniformity and the area radius, it is clear that the compensation film designed for the VA-LCD does not improve the VAC of the TN-

LCD compared to no compensation film at all. Further, neither the size nor uniformity of the VAC curves in FIGURE A and FIGURE B are acceptable.

Now, if the O-plate compensation film is designed specifically for TN- LCD, it improves the VAC. FIGURE C is a VAC of TN- LCD having an O-plate compensation according to US 6,831,722, and within the teaching of Okazaki..

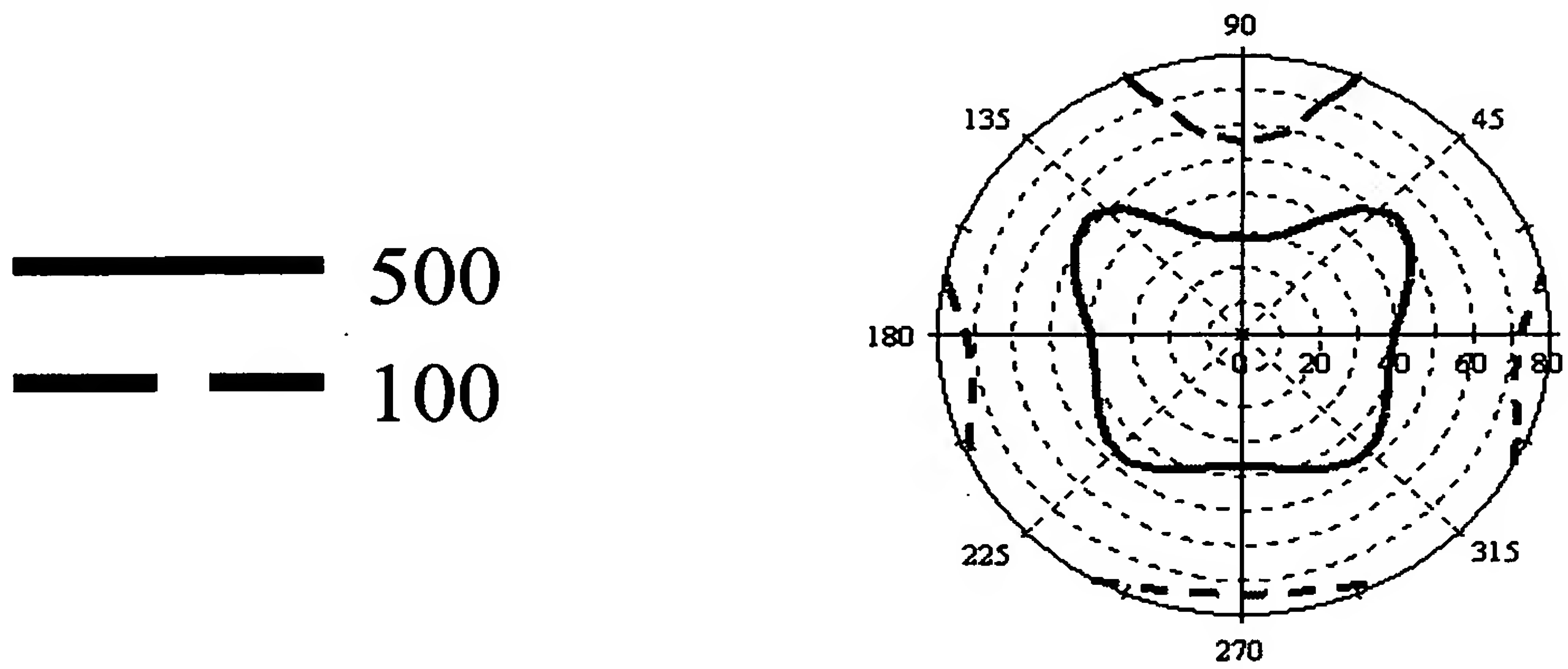


FIGURE C

Improvement over VAC shown in FIGURE A is apparent. Essentially all viewing area has contrast ratio higher than 100.

On the other hand, when the same O-plate compensation film is applied to a VA- LCD, the resulting VAC is severely degraded as shown in FIGURE D.

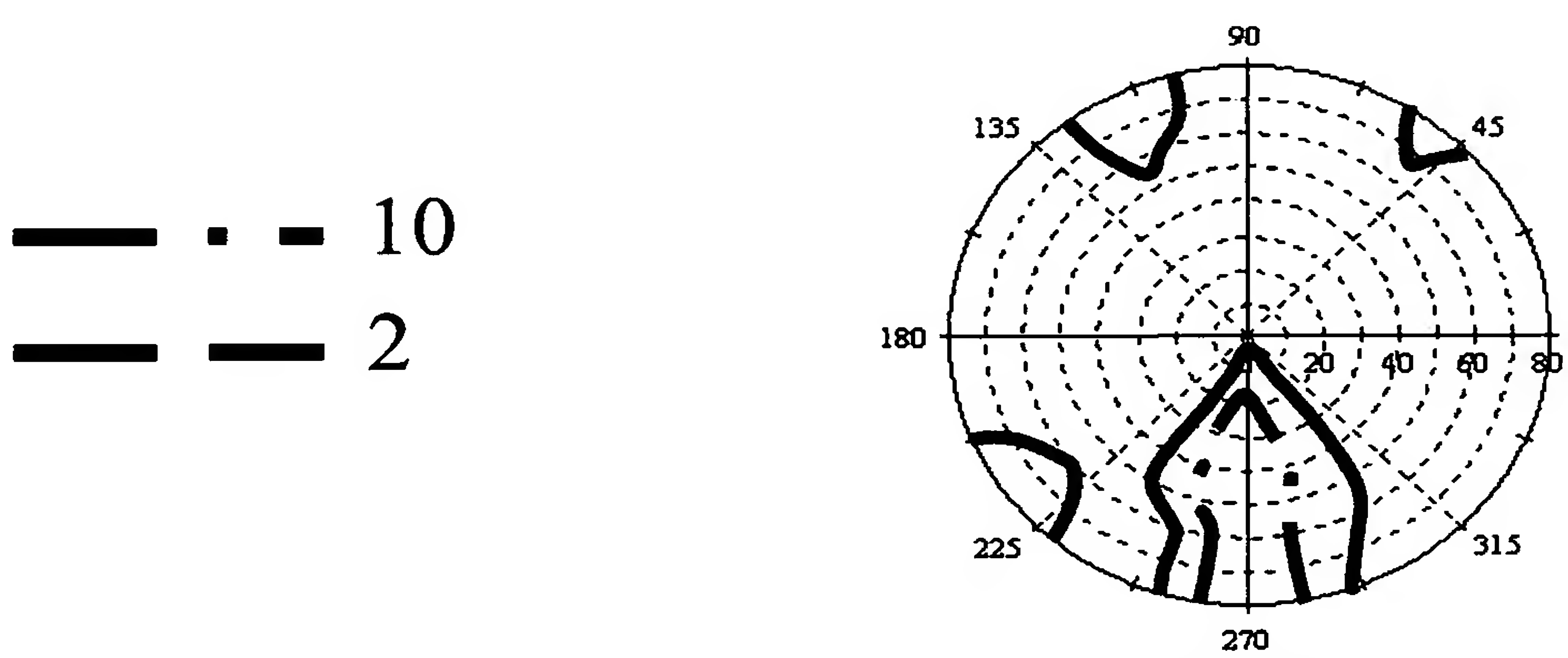


FIGURE D

Almost everywhere, the contrast lost its integrity, namely, the bright state and the dark state become opposite in brightness. The O-plate compensation film intended for TN- LCD only degrades the performance of the VA- LCD. Compare this with VAC of VA- LCD having O-plate compensation film properly designed for it such as shown

in FIG.9A, FIG. 9B, FIG. 9C. Thus, compensators useful for one mode (TN or VA) are not useful for the other.

B) Performance comparison between Aminaka negatively birefringent compensation film and the current invention positively birefringent compensation film.

US 6,081,312 teaches compensation film for VA-LCD (column 3 line 5-10) using discotic compound (= negative birefringent property) (column 11 line 10-20). The performance in terms of VAC of the compensation film is given in the Table 2 (column 27). The viewing angle according to the definition employed by Aminaka et al. in US 6,081,312 is "An angle that can view an image having a contrast ratio of not smaller than 10 along upward (U), downward (D), leftward (L) or rightward (R)." (column 27 (Remark)). None of the displays in TABLE 2 achieves a viewing angle higher than 70°. On the other hand, the compensation films according to the current application have viewing angles higher than 70°. For example, VA-LCD in EXAMPLE 1 has 75°, 75°, 90°, 90° in upward, downward, leftward and rightward directions, respectively. EXAMPLE 2 display has the corresponding viewing angles, 77°, 77°, 90°, 90°, respectively. Thus the current invention compensation film using positive birefringent anisotropy material offers significantly larger viewing angle than the compensation film using negative birefringent property. The overall conclusion is that the Aminaka compensator with only one anisotropic layer in the compensator is far less efficient than the two O-plate layer compensator of the invention.

C) Concerning Shimoshikiryoh et al., US 2004/0051832

US 2004/0051832 teaches a liquid crystal display where the LC cell has positive dielectric anisotropy ([007], claims 1 and 4). Thus, the liquid crystal molecules of the cell orient horizontally, or <u>parallel to the substrate, in the "off-state".</u>

By contrast, in the VA-LCD of the invention, the liquid crystal molecules of the cell align vertically, (specification: page 1 line 25-30; FIG 2B), that is <u>perpendicular to the substrate in the "off-state"</u>. Such a behavior is specific to the liquid crystal having negative dielectric anisotropy (see the attached copy of "Liquid Crystal Displays" page 6 line 14 – page 7 line 6, page 43 line 5- page 44 line 2). Thus, US 2004/0051832 does not suggest use of its compensation film in the type of VA-LCD of the present invention.

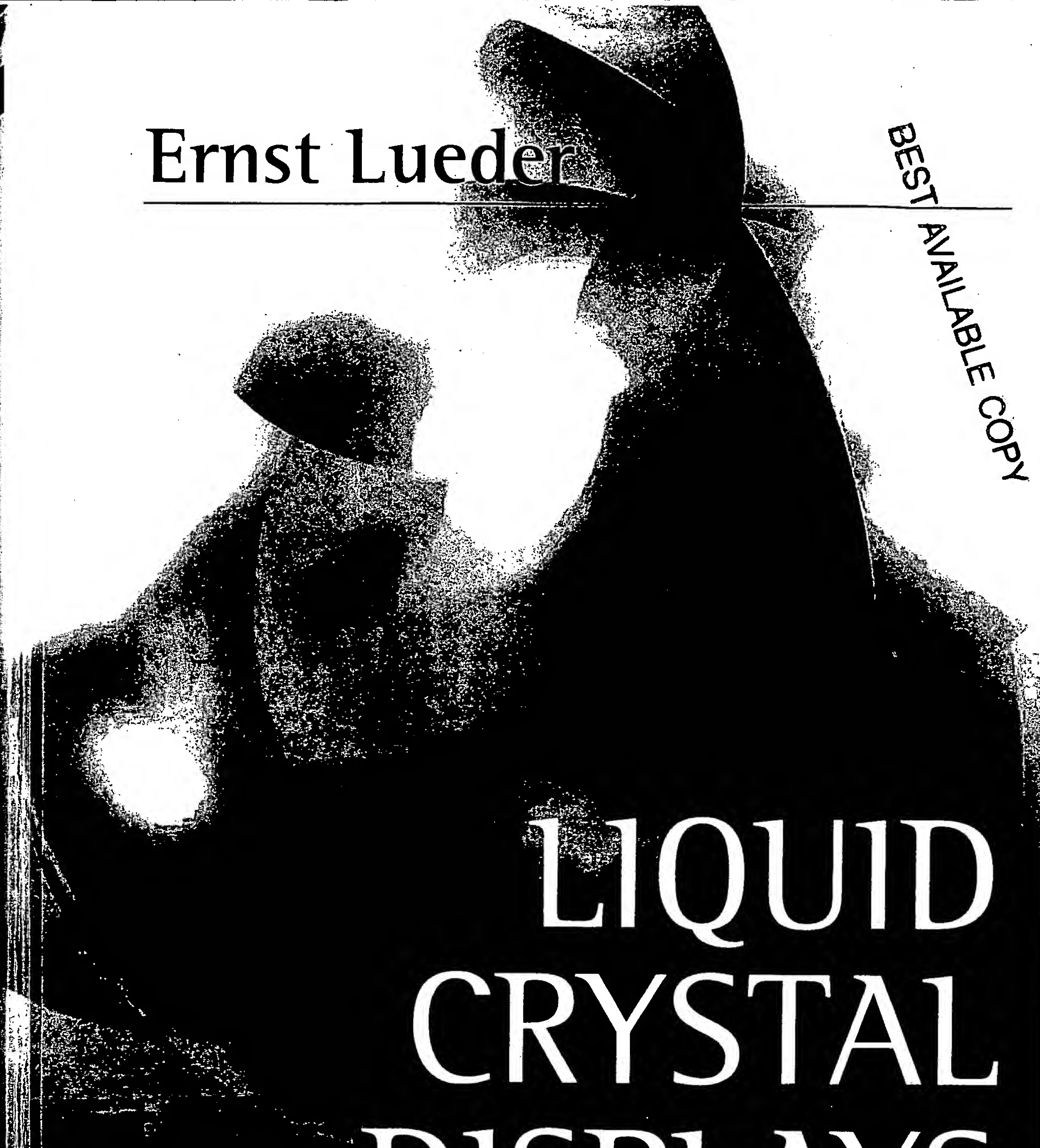
8. All statements made herein of my own knowledge are true and all statements made on information and belief are believed to be true. These statements are made with the knowledge that willful false statements and the like so made are punishable by fine or imprisonment, or both, under Section 1001 of Title 18 of the United States Code, and that such willful false statements may jeopardize the validity of the application or any patent issuing thereon.

Signed this 2 day of February, 2006

Tomohiro Ishikawa

Enclosure (1): Liquid Crystal Displays (excerpts)

Ernst Lueder



LIQUID CRYSTAL DISPLAYS

ADDRESSING SCHEMES AND ELECTRO-OPTICAL EFFECTS

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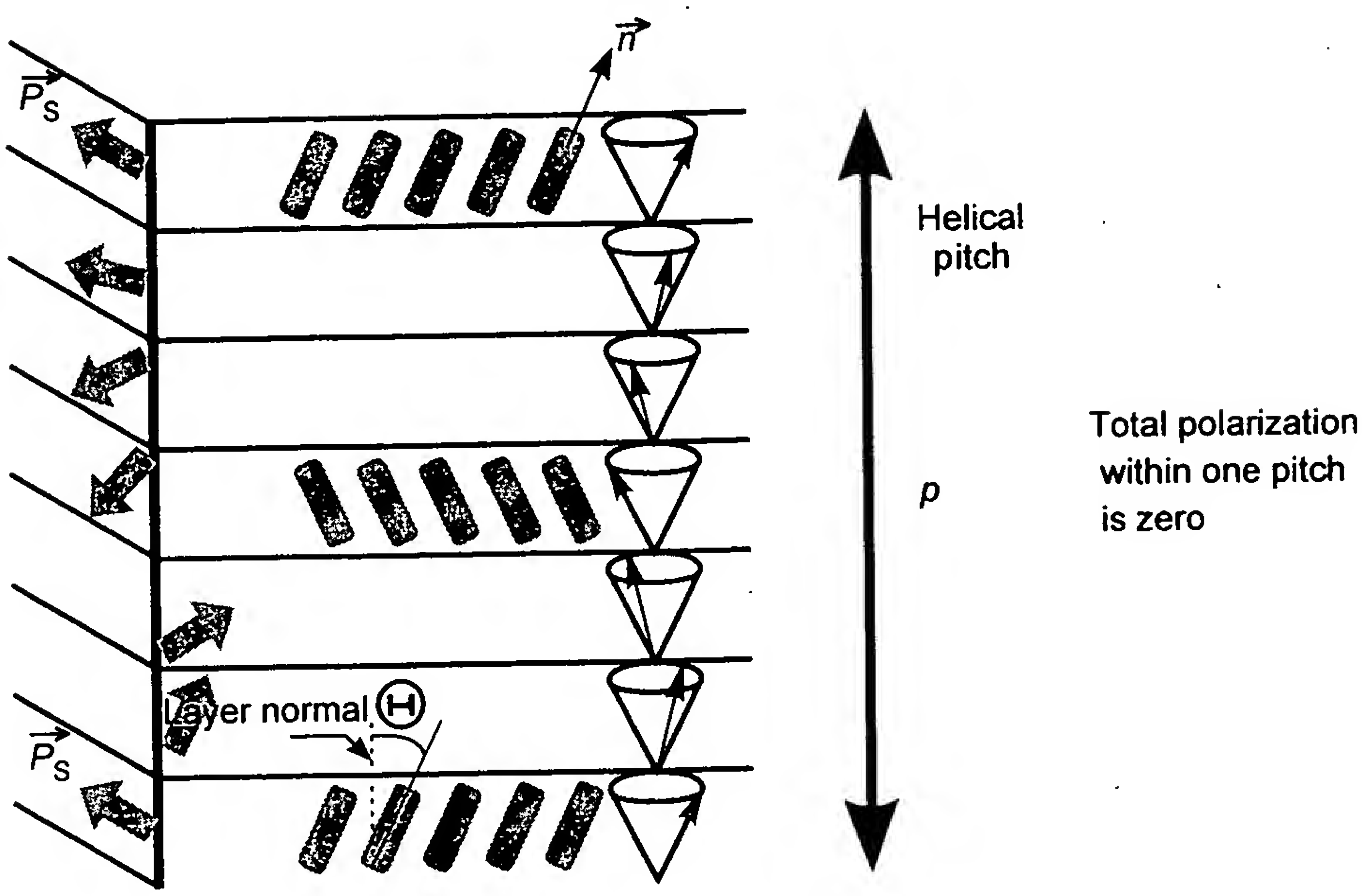

Figure 2.4 The helix in a layered structure of chiral smectic C liquid crystals with polarization $\vec{P}_s$ perpendicular to $\vec{n}$

The individual molecules have an angle Θ to this average director. The order parameter S of a phase is defined by (Tsvetkov, 1942)

$$S = \frac{1}{2}\langle 3\cos^2\Theta - 1\rangle, \tag{2.1}$$

where the bracket indicates that the average over a large number of molecules with angles Θ is taken. In a perfectly ordered state, $\Theta=0$, and hence $S=1$. A completely unordered phase has $S=0$. In typical nematic phases, S lies in the region of 0.4 to 0.7, indicating that the molecules are rather disordered.

The energy needed for a phase transition, e.g., from smectic A to smectic C, is characterized by a transition enthalpy in kJ/mol. Extensive investigations of phase transitions have revealed the temperature dependance of physical parameters such as the helical pitch, the viscosity or the elastic coefficients.

Due to the ordered structure, all phases between T_m and T_c are anisotropic, meaning that all dielectric, optical and mechanical properties depend upon the direction.

The dielectric constant is $\varepsilon = \varepsilon_r \varepsilon_0$, where $\varepsilon_0 = 8.854 \cdot 10^{-14}$ F/m stands for the permittivity in vacuum and ε_r for the relative dielectric constant. This means, as shown in Figure 2.1, $\varepsilon_r = \varepsilon_\parallel$ in the direction parallel to the director and $\varepsilon_r = \varepsilon_\perp$ perpendicular to the director, leading to the dielectric anisotropy

$$\Delta\varepsilon = \varepsilon_\parallel - \varepsilon_\perp. \tag{2.2}$$

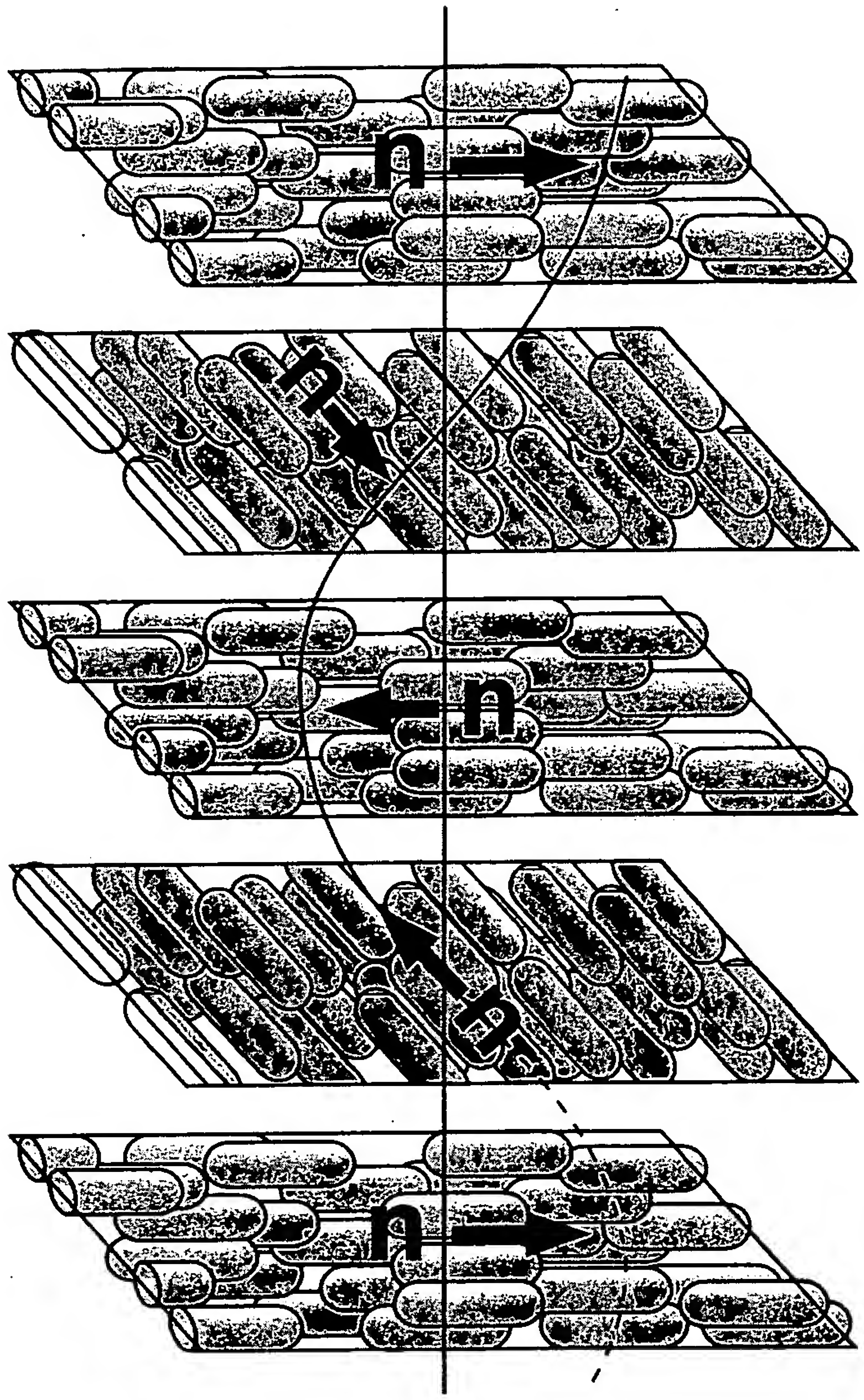

Figure 2.5 Helix of the cholesteric phase

Materials with $\Delta\varepsilon > 0$ are called p-type; their molecules align with the director parallel to the electric field, whereas in n-type materials with $\Delta\varepsilon < 0$, they align perpendicular to the field. This holds independent of the direction of the field vector. Values for $\Delta\varepsilon$ are found in the range from -0.8 to -6 and from 2 to 20. The addition of cyanogroups enlarges $\Delta\varepsilon$, whereas fluorine atoms in materials with $\Delta\varepsilon < 0$ lower $\Delta\varepsilon$ even further. Values for four materials are listed in Table 2.1.

The optical anisotropy Δn concerns the refractive indices n_0 for the ordinary beam of light, where the vector of the electrical field oscillates perpendicular to the optical axis that is perpendicular to the director and the refractive index n_e for the extraordinary beam of light,

For $\alpha = \pi/2$ the linearly polarized light in Figure 3.15 always encounters the refractive index $n_\perp$ independent of the tilt, and hence is independent of V (curve 7 in Figure 3.16), which is of no use for a phase shifter.

3.2.5 *The DAP cell or the vertically aligned cell*

The cell operating with the deformation of aligned phases, called the DAP cell (Glueck, 1995), is the inverse of the Fréedericksz cell. In the field-free state the LC molecules are perpendicularly (or in other words, homeotropically) aligned to the surface of both substrates, as depicted in Figure 3.17. This cell is also called a Vertically Aligned (VA) LCD. In this situation, incoming linearly polarized light with a wave vector $\vec{k}$ in parallel to the z-axis in Figure 3.17 does not encounter birefringence, and arrives at the second substrate with an unchanged state of its polarization. If the analyser is parallel to the polarizer, the full light can pass representing the normally white state. If the analyser is crossed with the polarizer, the light is blocked at the output for all wavelengths and independent of d. This is the normally black state. The cell exhibits an extremely good black state, since the blocking is again independent of λ. Further, the molecules on the orientation layer are also, contrary to the Fréedericksz cell, vertically aligned. A low black value in the denominator of the contrast in Equation (3.82) is most beneficial for a high contrast. The main attraction of the DAP cell is this extremely high contrast, reaching values of more than 500 : 1.

If an electrical field is applied, the LC molecules orient themselves perpendicularly to the field as $\Delta\varepsilon < 0$. This alignment corresponds to the same alignment of the Fréedericksz cell

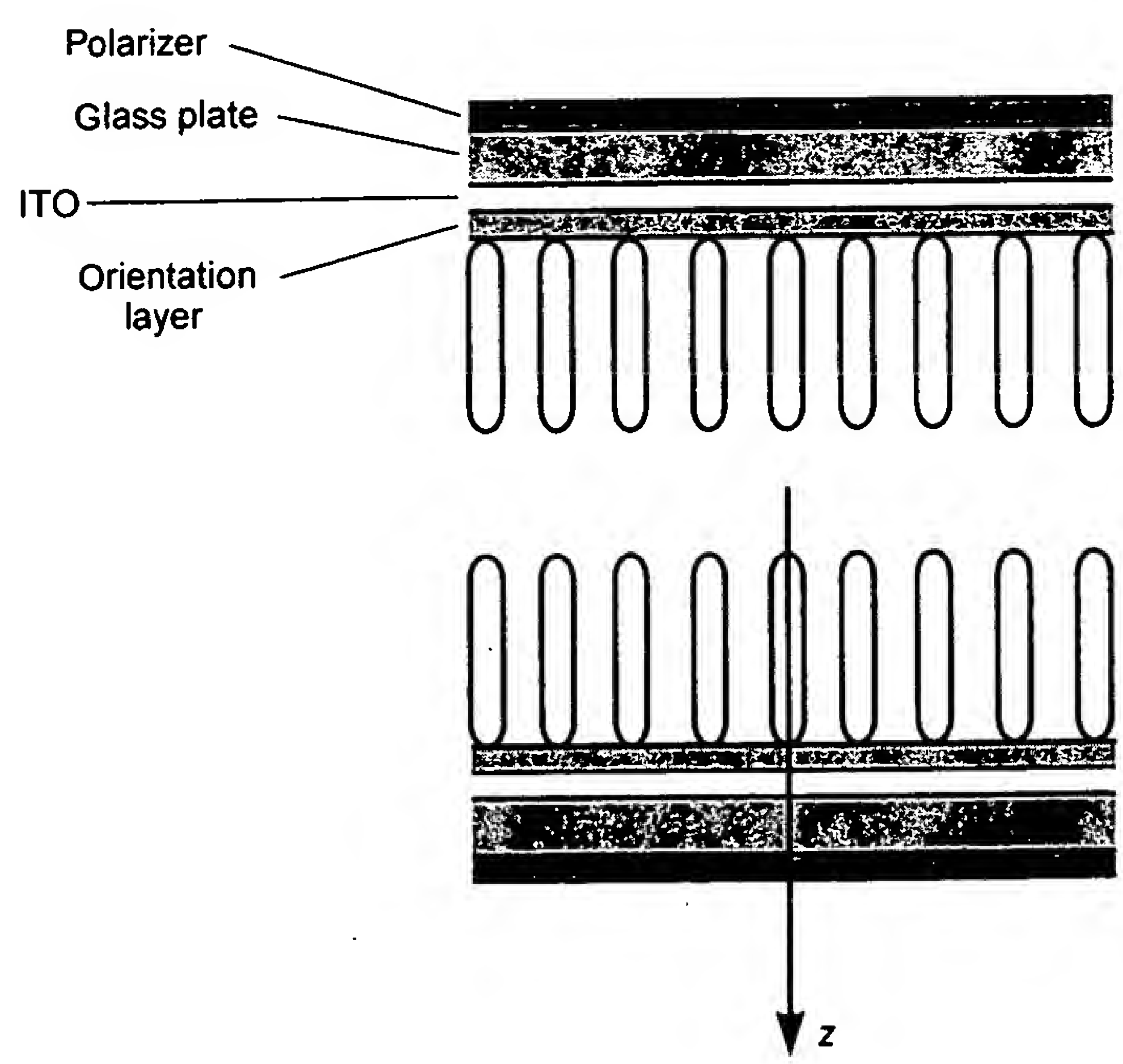

Figure 3.17 The DAP cell or Vertically Aligned (VA) cell in the field-free state

in the field-free state. Hence, all results in Equations (3.40) through (3.87) also apply to the DAP cell which is exposed to an electric field. The DAP cell is as well suited for phase-only modulators, as the pertinent Equations (3.90) and (3.95) also hold if a voltage V is applied. However, for the voltage-dependent refractive index $n(V)$, we obtain $n(V) \in \lfloor n_{\|}, n_{\perp} \rfloor$, but contrary to the Fréedericksz cell with $n_{\perp}$ for the lower voltage and $n_{\|}$ for the higher voltage. The homeotropic alignment of the molecules in the DAP cell requires special care. It is achieved by a spin-coated monomolecular silane-layer disolved in ethyl alcohol which is polymerized in the presence of humidity. The high polarity of silane thus generated anchors the polar LC molecules perpendicular to the surface. If a voltage is applied, all molecules are supposed to tilt in the same direction, since they have to end up all in parallel to each other and parallel to the plane of the substrates. This is realized by a small uniformly oriented pretilt of around 1° to 2° off the normal of the surface. A larger pretilt must be avoided, since it degrades the black state. The polymerized silane layer is uniformly rubbed with a carbon fibre brush to generate the grooves for the orientation of the molecules. As an alternative, this pretilted uniform orientation is produced with a very high manufacturing yield by a SiO_2 layer obliquely evaporated or sputtered under an angle of 2° off the normal. This alternative also achieves a very high contrast exceeding 500 : 1. The sputtering of this SiO_2 layer is explained in Figure 3.18. The DAP cell is, like a Fréedericksz cell, designed as a $\lambda/2$-plate with a retardation $\Delta nd = \lambda/2$, and hence $d = \lambda/2\Delta n$. For most commercially available LC materials exhibiting $\Delta n = 0.08$, this leads for $\lambda = 550$ nm to a cell thickness of $d = 3.4\,\mu$. The reflective version is a $\lambda/4$-plate with a thickness of $d = 1.7\,\mu$, which is often too thin for a high yield fabrication because small particles could easily cause shorts. The search for electro-optical effects with a larger cell thickness leads to the HAN cells and the Twisted-Nematic cells (TN-cells), which are covered in the next chapter and in Chapter 4.

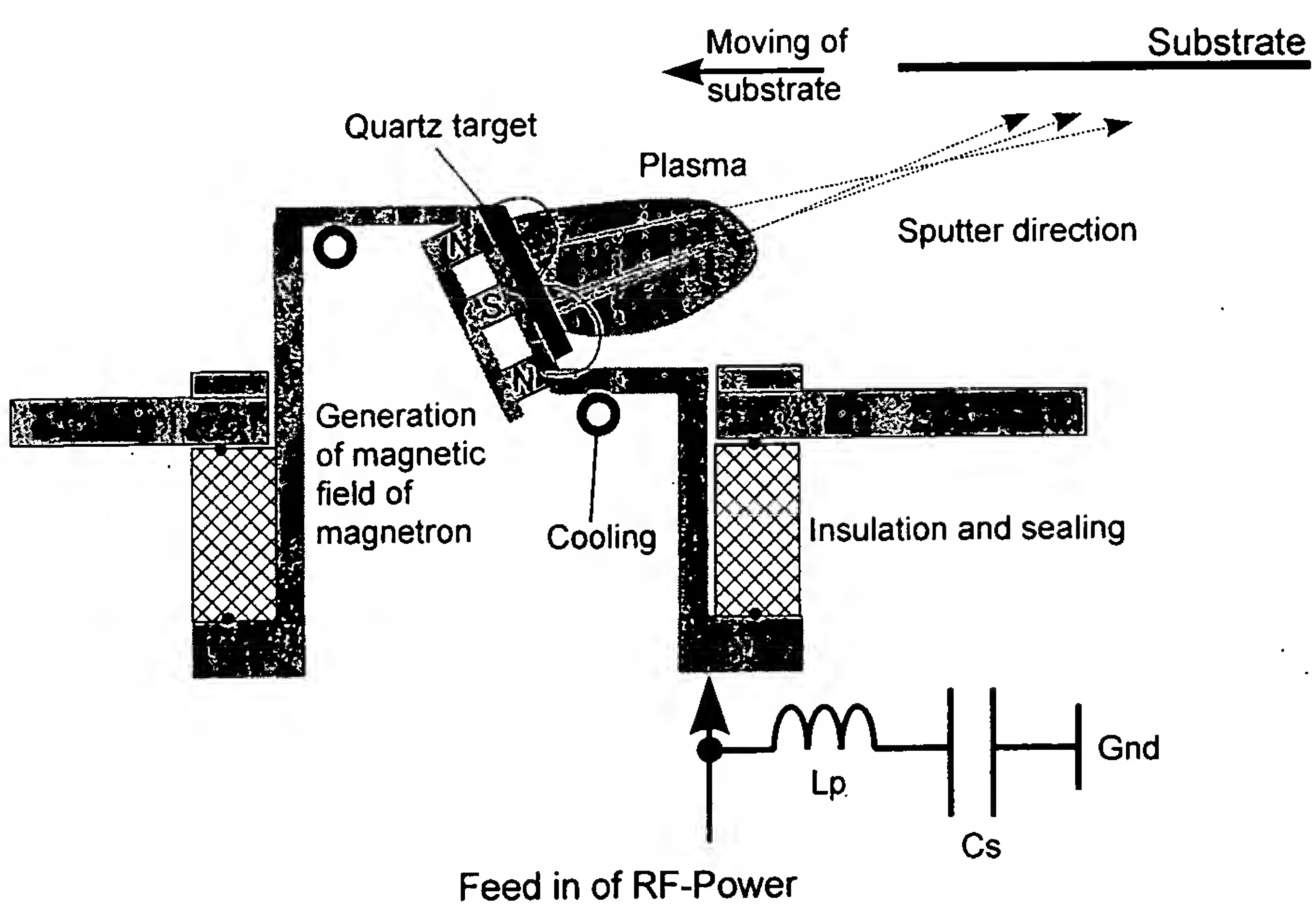

Figure 3.18 The sputtering of an SiO_2 orientation layer under an oblique angle of 70°

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